

(19) **FEDERAL REPUBLIC
OF GERMANY**

(12) **Published Application**
(10) **DE 197 39 527 A1**

(51) Intl. Class.⁶:
H 05 H 1/48
C 23 C 14/22

(21) Document Number: 197 39 527.9
(22) Date of Application: 9-9-97
(43) Date of Publication: 3-11-99

**GERMAN
PATENT AND
TRADEMARK OFFICE**

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(56) Publications to be considered in judging patentability:

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US 52 79 723
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WANG, Z.H., et al.: Spectroscopic studies of a solenoid filtered vacuum arc. In: J. Vac. Sci. Technol. A 13 (4), July/Aug. 1995, pp 2261-2265; ZHITOMIRSKY, V.N., et al.: Unstable arc operation and cathode spot motion in a magnetically filtered vacuum-arc deposition system. In: J. Vac. Sci Technol. A 13 (4), July/Aug. 1995, pp 2233-2240;

The following data are taken from the documents submitted by the applicant.

(54) **Vacuum Arc Plasma Source with Magnetic Particle Filter**

(57) The invention relates to cathodic vacuum arc discharges, in which disruptive particles are to be removed from the plasma. The object of the invention is a compact vacuum arc plasma source with a magnetic particle filter, in which the arc discharge burns in a stable manner without working gas.

The invention improves upon known vacuum arc plasma sources having magnetic particle filters in that the greatest axial distance between the limiting surface of the anode that faces the filters and the end surface of the cathode is designed to be smaller than the diameter of the anode aperture, and in that a compensating coil is positioned within the body of the anode and is arranged in an axial orientation

between the end surface of the cathode and the filter coil, wherein the compensating coil and the filter coil are connected opposite one another, so that their magnetic fields are oriented in opposite directions.

Furthermore, a specially positioned focusing coil and/or one or more specially positioned control coils are proposed. The cathode may take the form of a truncated cone or a disc.

Description

Cathodic vacuum arc discharges are already used in a broad range of applications, i.a. for generating metal plasmas and as metal ion sources, e.g. in film deposition and for ion implantation.

The plasma originates in the cathode spots, which form on the cathode surface and effect the erosion of the cathode material. In addition to plasma, the cathode spots also emit particles that range in size from a few 10 nm up to a few μm . In some applications in coating technology these particles adversely affect the quality of the deposited films; hence they must be removed from the plasma via filter assemblies.

Vacuum arc plasma sources containing magnetic particle filters have already been described in various sources. The individual solutions differ in terms of both discharge arrangement and filter principle.

One frequently used particle filter is comprised of a bent tube (USP 5433836). Another embodiment is comprised of several straight tube segments, which are assembled at corresponding angles (USP 5279723).

Depending upon the requirements in terms of the transmission of the filter and particle mobility, the deflection angle of this type of bent particle filter lies between 30 and 180°. An axially oriented magnetic field is generated in the tube and the plasma is guided along the field lines. By applying a positive bias voltage to the wall of the filter, the transmission can also be increased. The particles that are not affected by the fields become deposited on the filter wall in a lamellar fashion, which serves to prevent the backward scattering of the particles.

A further possibility is the use of a straight filter tube in conjunction with a centrally positioned aperture, which captures the particles (USP 4452686).

The geometry of the discharge arrangement in the above-described filter possibilities is as a rule axially symmetrical, with disc-, rod-, or truncated cone-shaped cathodes, the end surface of which is eroded by the arc discharge.

A dome-shaped arrangement, in which the arc burns on the outer surface of a cylindrical cathode, is described in USP 5282944.

USP 5480527 comprises a vacuum arc plasma source that uses an extended rectangular cathode in conjunction with a filter that is specially sized to correspond to this cathode shape.

All of the above-described vacuum arc plasma sources employ magnetic fields to guide the plasma. One result of this is an increase in the arc burning voltage, which leads to instabilities in the arc discharge, especially with the magnetic fields that are necessary for a maximum filter transmission.

This effect is counteracted by the use of a working gas (USP 5279723, USP 5282944) and/or auxiliary anodes at the filter exit (USP 5279723) or large-surface anodes

(USP 5433836), however the arc voltage remains substantially increased even with these measures.

When a vacuum arc plasma source is employed as an ion source for ion implantation, the use of a working gas is undesirable. The use of large-surface anodes means, in addition to high mechanical costs, a restriction of flexibility in the use of such sources and, under certain circumstances, increased space requirements in the related vacuum chambers.

The object of the invention is a vacuum arc plasma source with a magnetic particle filter, in which the arc discharge burns in a stable manner without working gas, and which is compact in its design.

In accordance with the invention, the object is attained through a special arrangement of magnetic fields. Essentially, the invention is based upon an axially symmetrical vacuum arc discharge arrangement comprised of a water-cooled cathode, an annular water-cooled anode, and an electrostatic shield that surrounds the cathode, with these components being mounted on a vacuum flange. Further, a known-in-the-art magnetic particle filter is used.

The solution according to the invention specifies that the greatest axial distance from the limiting surface of the anode that faces the filter to the end surface of the cathode is smaller than the diameter of the anode aperture, that a compensating coil is positioned within the body of the anode, that the compensating coil is arranged in an axial orientation between the end surface of the cathode and the filter coil, and that the compensating coil and the filter coil are connected opposite one another, so that their magnetic fields are oriented in opposite directions.

In one advantageous embodiment of the invention a focusing coil is provided, which surrounds the cathode in such a way that the distance of the end surface of the cathode from the center point of the focusing coil is less than half the sum of the length plus the internal radius of the focusing coil. The focusing coil generates a magnetic field that is oriented in the same direction as the filter magnetic field.

A further embodiment of the invention comprises one or more concentrically arranged control coils, which are positioned between the cathode and the vacuum flange and which serve to control movement of the focal point.

The cathode can be designed in the shape of a truncated cone or a disc.

The dimensions of the individual coils with respect to size, position, number of turns, and current intensity are designed by experts in the field within the listed restrictions, based upon the geometry of the plasma source. The goal in this is a magnetic field structure created via an overlapping of the magnetic fields that are generated by the individual coils, with said structure being characterized by an area of zero field intensity near the anode. In this manner, under equal magnetic field conditions, a maximal ion stream at the filter exit and a minimal arc voltage are achieved. Furthermore, even when an annular and thus small anode is used, the latter is increased relative to the arc voltage without magnetic fields only to a degree that does not require the use of a working gas in order to stabilize the discharge.

Below, the invention will be described in greater detail with reference to an exemplary embodiment. The attached drawings illustrate the following:

Fig. 1 an illustration of the principle of the invention in a partial cross section,

Fig. 2 the typical field line course of the magnetic field in the area of the discharge

arrangement and the filter intake.

The rotationally symmetrical vacuum arc discharge arrangement is essentially comprised of a water-cooled, disc-shaped cathode 1, which is surrounded at an axial displacement by an annular, also water-cooled anode 2, and by an electrostatic shield 3 that surrounds the cathode concentrically. These components are mounted on a vacuum flange 4, which is fastened via an intermediate flange 5 to the magnetic particle filter. The latter is comprised of an outer tube 6, which is fastened to the vacuum chamber, and which bears the filter coil 7, and an inner tube 8, which is comprised of a multitude of fins so as to prevent the backward scattering of particles, and which is electrically insulated from the remainder of the assembly. The cathode 1 is concentrically surrounded by the focusing coil 9. Behind the cathode 1 two control coils 10 are concentrically arranged. The compensating coil 11 is positioned in the water-cooling channel for the anode 2.

The filter coil 7 generates an axially oriented filter magnetic field in the inner tube 8. With a fixed filter magnetic field, the focusing magnetic field in the area in front of the end surface of the cathode is influenced primarily by the coils 7 and 11.

Variation of the focusing magnetic field is accomplished by varying the current intensity of the coils 7 and 11, wherein the permissible range of current intensities is relatively broad. It is important only that the current intensity of the coil 11 not be too small, as otherwise the area of zero field intensity could be located inside the anode cross section. Preferred is a variant in which the numbers of turns in the coils 7 and 11 are coordinated with one another such that when these coils are connected in series (i.e. equal current intensity) and the focusing coil 9 is without current, the magnetic field in the area of the end surface of the cathode is compensated. Then with the focusing coil 9 the focusing magnetic field between the end surface of the cathode and the filter intake can be adjusted independent of the filter magnetic field. In this, the optimal focusing magnetic field that is necessary for a maximal ion stream at the filter exit and at the same time a minimal arc voltage corresponds to an optimal positioning of the annular area of zero field intensity 12 near the anode. The use of the focusing coil 9 may also be eliminated completely, however, in which case the current intensity of the compensating coil 11 would be selected such that the filter magnetic field in the area of the cathode surface would be only partially compensated.

As cathode materials, chromium and aluminum were used. In each case, one of the control coils 10 is connected in the same or the opposite direction as the filter coil 7.

In the first case, cathode erosion occurs in the outer edge area. With an arc voltage of 100 V, a filter magnetic field of approximately 18 mT on the filter axis, a bias voltage of +20 V on the inner filter tube 8 and a deflection angle of 90 degrees, a maximal ion stream at the filter exit of 1.1 A using chromium and 1.85 A using aluminum is achieved, whereby the ion stream at the filter intake is 6 A or 10 A, respectively. The filter transmission amounts accordingly to 18.5% in each case. The minimal arc voltage for chromium amounts to approximately 24 V.

In the second case the cathode erosion takes place further inward, the ion stream at the filter exit is 10 to 20% lower, however the current density in the area of the filter axis is higher than in the first case. The minimal arc voltage for chromium in this case amounts to 25-26 V.

In order also to erode from the central area of the cathode, the outer control coil is connected in the same direction as the filter magnetic field and the inner control coil is

connected in the opposite direction. In this manner, with the help of the two control coils 10, the focal point can be guided over the entire surface of the cathode.

Patent Claims

1. Vacuum arc plasma source with a magnetic particle filter, comprised essentially of a water-cooled cathode (1), a water-cooled, annular anode (2), an electrostatic shield (3) that surrounds the cathode, a vacuum flange (4), an outer filter tube (6), a filter coil (7), and an inner filter tube (8) that is

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comprised of numerous fins, **characterized in that** the greatest axial distance from the limiting surface of the anode (2) that faces the filters (6-8) to the end surface of the cathode is designed to be smaller than the diameter of the anode aperture, in that a compensating coil (11) is positioned within the body of the anode(2), in that the compensating coil (11) is arranged in an axial orientation between the end surface of the cathode (1) and the filter coil (7), and in that the compensating coil (11) and the filter coil (7) are connected opposite one another, so that their magnetic fields are oriented in opposite directions.

2. Vacuum arc plasma source with a magnetic particle filter in accordance with claim 1, characterized in that a focusing coil (9) is employed, which surrounds the cathode (1) in such a way that the distance of the end surface of the cathode from the center point of the focusing coil (9) is less than half the sum of the length plus the inner radius of the focusing coil (9).

3. Vacuum arc plasma source with a magnetic particle filter in accordance with claim 1 or 2, characterized in that one or more control coils (10) are arranged concentrically relative to the cathode (1), between the cathode (1) and the vacuum flange (4).

4. Vacuum arc plasma source with magnetic particle filter in accordance with one of claims 1 through 3, characterized in that the portion of the cathode (1) that is used for material erosion is in the shape of a truncated cone.

5. Vacuum arc plasma source with a magnetic particle filter in accordance with one of claims 1 through 3, characterized in that the cathode (1) is disc-shaped.

2 pages of drawings attached

Figure 1:

Wasser = Water